Journal of Atmospheric and Solar-Terrestrial Physics 128 (2015) 24–32

Contents lists available at ScienceDirect

Journal of Atmospheric and Solar-Terrestrial Physics

journal homepage: www.elsevier.com/locate/jastp

Long term changes in the ionosphere over Indian low latitudes: Impact of greenhouse gases

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ARTICLE INFO

Article history:
Received 30 December 2013
Received in revised form
22 February 2015
Accepted 5 March 2015
Available online 6 March 2015

Keywords:
Ionosphere
Long term changes
Greenhouse gases

ABSTRACT

Increased concentration of greenhouse gases due to anthropogenic activities warm the troposphere and have a cooling effect in the middle and upper atmosphere. Ionospheric densities and heights are affected due to cooling. Carbon dioxide is one of the most dominant gases for the cause of long term ionospheric trends along with other radiatively active greenhouse gases. Regular ionospheric soundings are made over Ahmedabad (23.1°N, 72.7°E), since 1953. Long term changes in the ionosphere as a consequence of the cooling of the mesosphere and thermosphere due to the increased concentration of greenhouse gases have been studied. Ionospheric observations over Ahmedabad, a low latitude station in the anomaly crest region, for the years 1955–2003 are examined to study the long term changes in the critical frequencies of the various ionospheric layers and the height of the maximum ionization as characterized by h_pF_2. A decrease in f_oF_2 (1.9 MHz for midday, 1.4 MHz for midnight) and h_pF_2 (18 km for midday, 17 km for midnight) during about five decades are noted. An increase is noted in f_oF_1 (0.4 MHz). The f_oF_2 data are also examined over an equatorial station Kodaikanal (10.2°N, 77.5°E), situated near the magnetic equator for the years 1960–1995 and a decrease of 0.5 MHz for midday and 0.7 MHz for midnight are noted in ~35 years.

1. Introduction

In the recent years there has been a great concern over the increase in the concentration of the greenhouse gases due to anthropogenic causes, and the consequences in the global climate (warming). The 0.6 K increase in global temperature during the twentieth century (e.g., Intergovernmental Panel on Climate Change (IPCC), 2007) has been attributed mostly to the increasing atmospheric concentration of greenhouse gases. These gases cause warming in the lower atmosphere and an opposite, cooling effect in the upper atmosphere. Brasseur and Hitchman (1988) modeled the effect of increased carbon dioxide up to about 70 km and found that cooling rather than warming would be present near the stratopause. This effect of greenhouse gases on the upper atmosphere has been referred to as "greenhouse cooling" (Cicerone, 1990).

Roble and Dickinson (1989) were the first to demonstrate that the mesosphere and thermosphere would cool by 10 K and 50 K respectively due to a doubling of carbon dioxide (CO_2) and methane (CH_4) by using a global mean model of the mesosphere, thermosphere and ionosphere. They also reported that the ionospheric structure would alter with the lowered E and F region peaks due to the compositional redistribution that will occur in association with the change in temperature profile.

Further modeling studies by Rishbeth (1990), and Rishbeth and Roble (1992) broadened these results to the thermosphere–ionosphere system. Rishbeth (1990) examined the changes in the ionosphere due to the global cooling on the basis of the basic theory of ionosphere for mid latitude during equinox under quite geomagnetic and solar minimum condition. According to his calculations the cooling and associated compositional changes as described by Roble and Dickinson (1989) would lower the E and F_2 layer peaks by ~2 km and ~20 km, respectively. Later Rishbeth and Roble (1992) considered the effect of global cooling using the three dimensional TIGCM (Thermosphere/Ionosphere General Circulation Model) developed at NCAR for both solar minimum and maximum conditions during December solstice. The results obtained for different latitudes and longitudes showed, on an average, reduction of h_mF_2 by 10–20 km for solar minimum and 10–15 km for solar maximum. The changes in f_oF_2 were less than 0.5 MHz. They also studied the changes in electron density as a function of height and latitude. The largest changes were seen to occur in the F_1 layer near 180 km with 50% increase at mid

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http://dx.doi.org/10.1016/j.jastp.2015.03.002
1364-6826/

latitudes. The changes in E layer were very small (up to 5%). Laštovička and Pancheva (1991) were the first to show observational results. Subsequently, changes in thermospheric density have been detected and characterized. It is believed that the upper atmosphere contracts due to cooling, and consequently thermospheric densities decrease significantly. This has been confirmed through the long-term observations of atmospheric drag on satellite orbits (e.g., Keating et al., 2000; Marcos et al., 2005; Emmert et al., 2008 and references therein).

Long-term changes and trends in the upper atmosphere have been studied much less extensively than those in the lower atmosphere, but the topic has grown over the past two decades into an active area of research (e.g., Laštovička et al., 2012). Long-term decrease in height and increase/decrease in electron density in the ionospheric E and F_1 regions have been studied extensively (e.g., Bremer, 1992, 1998; Jarvis et al., 1998; Sharma et al., 1999, Laštovička and Bremer, 2004, and reference therein), and both positive and negative trends in the ionospheric F_2 region have been reported (e.g., Bremer, 1992; Ulich and Turunen, 1997; Sharma et al., 1999; Danilov and Mikhailov, 1999; Laštovička et al., 2006b and references therein). Recent studies on long-term trends in the ionospheric F_2 layer (e.g., Danilov, 2009; Bencze, 2009; Qian et al., 2009; Cnossen and Franzke 2014, and references therein) have been very pertinent and expressive.

Mielich and Bremer (2013) have derived Ionospheric trends over several stations with an excellent monthly median data of f_oF_2 and M(3000)F_2, using a twofold regression analysis depending on solar and geomagnetic activity. They found that the solar 10.7 cm radio flux (F10.7) is a better index for the description of the solar activity than the relative solar sunspot number (R_z) as well as the solar EUV proxy (E10.7). Their second major finding was the global mean f_oF_2 and h_mF_2 trends are in better agreement with model calculations of an increasing atmospheric greenhouse effect between 1948 and 2006.

There are several drivers of the long-term trends in the ionosphere, and these were studied extensively by several workers (e.g., Mikhailov, 2006; Akmaev et al., 2006; Qian et al., 2006; Cnossen and Richmond, 2008; Elias, 2009, Elias et al., 2011; and reference therein).

Several studies of long term trends in various parameters of the atmosphere and ionosphere brought out very interesting results. Laštovička et al. (2012) presented a comprehensive review on long term trends and changes in the upper atmosphere and ionosphere. Recently, Jacobi (2013) studied long-term trends and decadal variability in the upper mesosphere and lower thermosphere gravity waves at mid-latitudes and found increasing mesospheric zonal wind jet along with increasing gravity wave variances in both the seasons winter and summer. Changes in Ionospheric F_2 region (e.g., Bremer, 1992,1998; Ulich and Turunen, 1997; Upadhyay and Mahajan, 1998; Sharma et al., 1999; Danilov, 2009; Bencze, 2009; Qian et al., 2009), changes in water vapor (e.g., Bremer et al., 2009; Lübken et al., 2009), mesosphere–lower thermosphere dynamics (e.g., Jacobi et al., 2006; Merzlyakov et al., 2009 and reference therein), were extensively studied. Furthermore, trends of mesospheric temperature have been studied by several groups using ground-based instruments, viz. Lidar, etc., by rocket sonde, and using satellites observations (e.g., Hauchecorne et al., 1991; Clemesha et al., 1992; Bittner et al., 2002; Golitsyn et al., 2000; Lübken, 2001; Nielsen et al., 2002; She et al., 2009, and references therein). Modeling study by Roble and Dickinson (1989) predicted a cooling of about −10 K in the mesosphere from a doubling of CO_2 and CH_4. Later several modelers studied long term trends, which further confirmed and augmented his work (e.g., Gruzdev and Brasseur, 2005; Schmidt et al., 2006; Fomichev et al., 2007; Garcia et al., 2007 and references therein). Beig et al. (2003) presented an elaborate review of observational and modeling results on long term changes and trends and concluded that overall, there is cooling of the order of −2 to −3 K/decade in the altitude region from 50 km to 80 km whereas there is no significant trend in the mesopause region from 80 km to 100 km. A comprehensive update presented by Beig (2006), significantly augmented earlier findings, and further confirmed the findings reported by other groups.

Bremer (1992) using ionospheric measurements at a mid latitude station, Juliusruh (54.6°N, 13.4°E) in Germany detected a decrease in h_mF_2 (0.45 km/year in winter and 0.12 km/year in summer) using the MUF data over the period 1957–1990. Ulich and Turunen (1997) reported the changes in the F layer peak at a high latitude station, Sodankyla (67.4°N, 26.7°E) from the data obtained during 1957–1995 and showed that peak height decreases at a rate of 0.39 km/year. Seasonally, the decrease was maximum during July (0.88 km/year). Jarvis et al. (1998) have reported similar decreases in the altitude of peak ionization at Argentine Islands (65°S, 64°W) and Port Stanley (52°S, 58°W) located in the high and mid latitudes of the Southern Hemisphere. There have been studies covering several stations based on the data published by the World Data Center. Upadhyay and Mahajan (1998) examined data of 34 years at 31 stations and found trends in f_oF_2 and h_mF_2 to be positive, negative or insignificant. Bremer (1998) analyzed data from 31 European stations and found lowering of E region height, h'E; increases in f_oE and f_oF_1 in agreement with the model predictions. However the results for F_2 region were complex with the stations west of 30°E showing negative trends in f_oF_2 and h_mF_2 and the stations east of it showing positive trends.

In recent years a comprehensive study of changes in the upper atmosphere and ionosphere has been brought out through observational and modeling studies (e.g., Laštovička et al., 2008; Laštovička, 2009). They found that electron density in the E and F_1 regions has increased and the altitude of the E region of the ionosphere has decreased. These trends are consistent with modeling results, and with the hypothesis of global cooling and contracting of the upper atmosphere proposed by several workers (e.g., Rishbeth and Roble, 1992; Qian et al., 2009).

There have been several studies on the long term changes in the ionosphere globally but most of them are focused on high and mid-latitude observations and over the low latitudes studies are relatively scanty. In earlier work Sharma et al. (1999) have reported some results on long term trends in a short paper, in form of a letter, and used observations from 1955 to 1996 over Ahmedabad (23.1°N, 72.7°E), which is a low latitude station near the northern crest of the Equatorial Ionization Anomaly (EIA). Present study is comprehensive one and based on the Ionosonde observations over Ahmedabad for longer period from 1955 to 2003. Observations over another station, Kodaikanal (10.2°N, 77.5°E), located in the equatorial region and close to the magnetic equator, have been also examined to study the long term trends and changes in the ionosphere over low latitude locations.

2. Data base and method of analysis

Regular radio sounding of the ionosphere over Ahmedabad started in 1953 when an automatic ionosonde, British Mk II, was set up at the Physical Research Laboratory. This was later, replaced by an American C4 model in 1976 and subsequently a digital KEL ionosonde was in operation since 1993. Checks for consistency in data were made at the times of changes of ionosondes. The ionograms for the 37 years (1966–2003) have been scaled by a single person. The parameters used in the present study have uniformity and reliability therefore for long term studies.

The ionospheric parameters show large seasonal and solar cycle variations. To remove the seasonal variation, the long-term